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Search for Ultra-High Energy Emission from Geminga and Five Unidentified EGRET Sources

The CYGNUS Collaboration

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Abstract

Data from the CYGNUS extensive air shower array were searched for continuous ultra-high energy (UHE) gamma radiation from five unidentified EGRET sources and from the Geminga pulsar. No evidence for continuous emission from any of these objects was found. Data in the Geminga source bin were also searched for pulsed emission using the recent EGRET ephemeris (237 ms period). No evidence of a periodic signal was found. The 90% confidence level upper limit on the continuous gamma-ray flux above 80 TeV for Geminga is 7.9×10^{-14} cm^{-2} s^{-1}.

1. INTRODUCTION

The Energetic Gamma-Ray Experiment Telescope (EGRET) on the Compton Gamma Ray Observatory has observed six previously unidentified gamma ray sources. These sources (Hartman 1993) have no known X-ray, radio, or optical counterparts, and cover a substantial range in galactic latitude and longitude. Five of these sources are in the field of view of the CYGNUS extensive air shower experiment.

EGRET has also observed gamma ray emission from one of our close (100 pc) galactic neighbors, the Geminga pulsar (Bertsch *et al.* 1992). Geminga is of particular interest, since the gamma ray (Bertsch *et al.* 1992, Bignami and Caraveo 1992, and Mattox *et al.* 1992) and X-ray detections (Halpern and Holt 1992) indicate it is similar to the Crab and Vela pulsars. Especially appealing for UHE experiments are the reported detections of periodicity at energies of TeV (Vishwanath *et al.* 1992 and Bowden *et al.* 1993).

The COS B and EGRET experiments have measured ephemerides for the Geminga pulsar. The COS B ephemeris (Hermsen *et al.* 1992) is useful for several years after 1979, but the phase uncertainty becomes prohibitively large by 1986, when the CYGNUS experiment began taking data. The EGRET ephemeris (Mayer Hasselwander *et al.* 1992) is contemporaneous with the CYGNUS experiment.

2. THE CYGNUS EXPERIMENT

The CYGNUS extensive air shower experiment began operation in April 1986 with 50 scintillation detectors located around the Los Alamos Meson Physics Facility beam stop (106°15′ W, 35°52′ N, 2120 m above sea level) in Los Alamos, NM. The array has been significantly expanded since that time. This analysis uses data taken with the CYGNUS I array. The present CYGNUS I array consists of 108 scintillation detectors,

covers 22,000 m^2, and has an event rate of 3.5 s^{-1}. A more detailed description of the experiment can be found elsewhere (Alexandreas *et al.* 1992).

For showers initiated by cosmic rays, the most probable and median detected primary energies are $\sim$ 50 TeV and $\sim$ 100 TeV, respectively (Alexandreas *et al.* 1993a). Assuming gamma-ray sources and cosmic rays have similar energy spectra at the top of the atmosphere, the median detected primary energy for gamma-ray-initiated showers from a source passing through zenith is $\sim$ 60 TeV, and increases with increasing zenith angle.

3. SEARCH TECHNIQUES AND RESULTS

Analysis of the solar and lunar shadows (Alexandreas *et al.* 1993a, Alexandreas *et al.* 1991a) has demonstrated the average CYGNUS-I angular resolution to be 0.7 degrees. The angular bin for a potential source is 2.0° wide in declination (δ) by $2.0°/\cos\delta$ (to the nearest 0.2°) wide in right ascension (α) centered on the source position. This maximizes the statistical significance of a signal for an angular resolution of 0.7°. The number of on-source events, N_s, is the total number of events whose celestial coordinates fall in the source bin. The number of expected background events, N_b, is determined from the data (see Alexandreas *et al.* 1991b).

Applying this method to the 242 million events taken between 3 April 1986 and 27 January 1993, the number of on-source events and the estimated number of cosmic ray background events have been found for the six EGRET sources (Table 1). There is no evidence for continuous emission from any of the sources examined. Also given in Table 1 are the coordinates of each source, the statistical significance of each excess, σ, computed using the prescription of Li and Ma (Li and Ma 1983), and the 90% confidence level upper limits on the number of excess events in the source bin, expressed as a fraction of the cosmic-ray background (f_{90}). f_{90} is converted into a 90% confidence level upper limit on the gamma-ray flux (ϕ_γ) above the median gamma-ray energy in the source bin, E_m, using

$$\phi_\gamma \; \frac{f_{90}\phi_{cr}(>E)\Omega}{0.72R_\gamma}, \qquad (1)$$

where $\phi_{cr}(>E) = (1.8 \pm 0.5) \times 10^{-5} E^{-1.76\pm0.05}$ cm^{-2} s^{-1} sr^{-1}) (Burnett *et al.* 1990, Alexandreas *et al.* 1993a) is the all particle cosmic ray flux above E (in TeV), Ω is the solid angle of the source bin (1.2×10^{-1} sr), R_γ is the ratio of the detection efficiency for photons to the detection efficiency for cosmic rays (Alexandreas *et al.* 1993a), and 0.72 is the fraction of the signal events expected to be in the source bin.

The gamma ray flux limits in Table 1 do not account for the attenuation of VHE gamma rays due to interactions with the 2.7 K cosmic microwave background radiation field (CMBR). Since Geminga is nearby, attenuation by the CMBR has no affect on the gamma ray flux limit. If the five unidentified EGRET sources are extragalactic, the flux limits could be significantly larger (Alexandreas *et al.* 1993b).

The events in the Geminga source bin were also analyzed for evidence of 237 ms periodicity. To maintain a phase uncertainty < 0.1 the pulsed analysis only uses data taken between 12 September 1989 and 27 January 1993 ($\sim$ 280 million events). Each event was processed to the B1950.0 epoch and was barycentered using the JPL DE200 ephemeris. The recent EGRET ephemeris was used to calculate the phase of each event. The corresponding phasegram (Figure 1) shows no evidence for periodicity.

4. CONCLUSIONS

Data taken with the CYGNUS extensive air shower array between 3 April 1986 and 27 January 1993 was examined for continuous emission from Geminga and five unidentified EGRET sources. No evidence of continuous gamma ray emission was found. In addition, events in the Geminga source bin were examined for evidence of the 237 ms pulsation period. No evidence of a periodic signal was seen. Flux limits have been calculated at the 90% confidence level, assuming that the five unidentified are within the galaxy.

Source	δ	α	N_s	N_b	σ	f_{90}	ϕ_γ	E_m
Geminga	17.8	97.8	69243	68677	+2.2	0.014	7.9	80
J0430+29	29.1	66.7	90812	90869	0.2	0.005	1.0	70
J1220+16	17.0	185.0	59542	59781	1.0	0.005	3.0	80
J1221+23	23.9	184.8	82146	82663	1.8	0.004	2.5	70
J1840+58	58.6	280.0	68095	68367	1.0	0.005	2.3	90
J2024−08	8.3	305.5	4912	4963	0.7	0.020	2.9	210

Table 1. The results of the search for continuous emission. For each source we give the coordinates (J1950), the total number of observed (N_s) and expected (N_b) events and the corresponding statistical significance. Also given are f_{90} and the corresponding upper limit to the flux (ϕ_γ) for each source above the median detected energy (E_m) for that source declination. The units for the flux limits are $10^{-14}\,cm^{-2}s^{-1}$.

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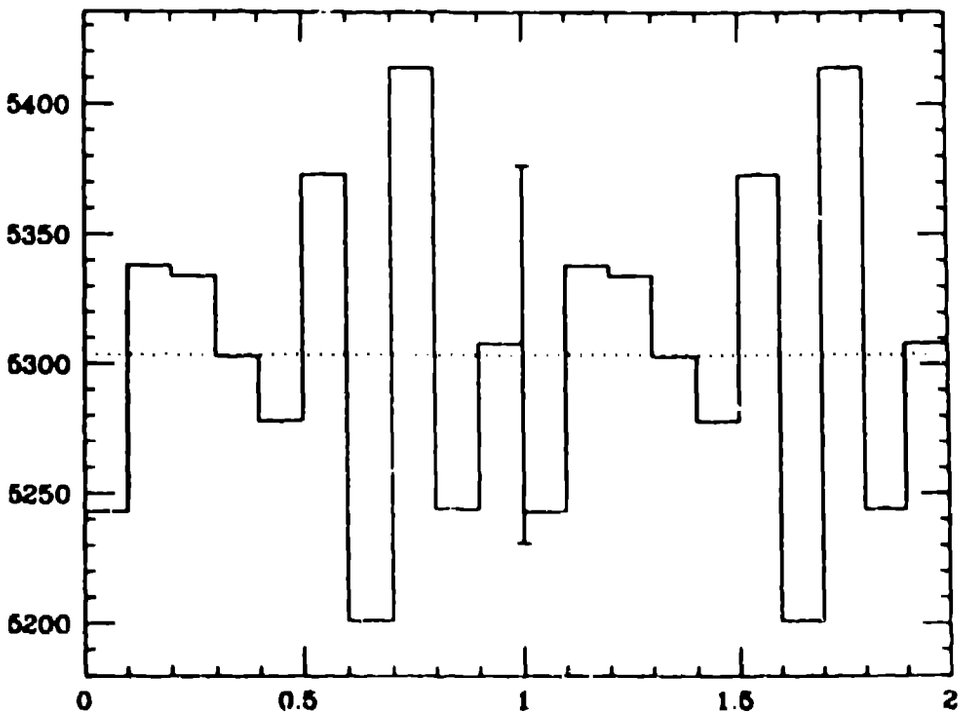

Figure 1: Phaseogram of the data in the Geminga source bin. Note that the phase range is from 0 to 2. The dotted line is the mean number of entries per bin. A typical 1 standard deviation error is shown.